**BBC RD 1984/16**

**RESEARCH DEPARTMENT** **REPORT**

# Television Animation Store: digital chroma-key and mixer units

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**December 1984**

**BBC RD 1984/16**
UDC 621.377.6: 621.397.13

# TELEVISION ANIMATION STORE: DIGITAL CHROMA-KEY AND MIXER UNITS

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## Summary

*The digital chroma-key unit described in this report is incorporated in a digital video storage system which is used in the preparation of animated picture sequences obtained from an electronic rostrum camera. The circuitry operates on digital YUV video signals and can generate key signals from any selected colour in the foreground picture; these key signals are then used to replace the areas of the chosen colour in the foreground picture by a background picture using linear, additive key techniques. In addition, key signals can be obtained from the foreground's luminance component. As well as the technical details of the unit, the report includes a description of its ergonomic control and discusses problems associated with digital processing.*

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**BRITISH BROADCASTING CORPORATION**

December, 1984
(PH-269)

# TELEVISION ANIMATION STORE:
# DIGITAL CHROMA-KEY AND MIXER UNITS

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# TELEVISION ANIMATION STORE: DIGITAL CHROMA-KEY AND MIXER UNITS

V.G. Devereux, M.A.

## 1. Introduction

The digital chroma-key* equipment discussed in this report forms part of a digital video storage system, to be referred to as an animation store, which is used in the preparation of animated picture sequences obtained from an electronic rostrum camera.[1,2] The animation store is capable of recording up to 815 television pictures in *YUV* digital component form. (*Y*, *U* and *V* represent the luminance and two colour-difference components.) Pictures can be recorded and replayed either individually or as a sequence at normal television rates. The main storage device is a computer type disc drive unit which has been modified to operate at higher than normal data rates and with data transferred to or from nine recording surfaces in parallel.[3] The system is controlled by a mini-computer for which extensive software has been developed so that all the required picture processing and rostrum camera control can be defined by simple information entered via dedicated control keyboards and using special VDU displays.

Within the animation store, a programmable digital mixer and chroma-key generator provide the means whereby pictures may be combined to generate effects similar to those achieved with the multiple exposure and travelling matte techniques used with conventional film rostrum cameras. The chroma-key circuitry can generate key signals from any colour in the foreground picture; in addition, "black" or "white" key signals can be obtained from the foreground's luminance component. This circuitry provides smooth transitions from foreground to background pictures with no impairment resulting from the sampled nature of the digital video signals; it can also produce transparency and shadow effects.

Wideband key signals can be derived from *YUV* component video signals with each component sampled at 12 MHz. These 12:12:12 MHz *YUV* signals are obtained directly from the RGB rostrum camera inputs to the stills store. Narrower band keys can be derived from any stored *YUV* signal for which the sampling rates are 12, 4, and 4 MHz respectively. (These sampling rates had to be fixed long before the 13.5, 6.75 and 6.75 MHz rates given in CCIR Rec. 601 were established). These keys can be stored as a 12 MHz sampled digital signal for later used. An external signal applied to a separate input to the stills store can be combined with the internally generated key.

The chroma-key processing is based on "linear additive" techniques described by Oliphant;[4]* similar techniques are used in equipment described by Hughes.[5] More conventional "non-linear/multiplicative" techniques described in references,[6,7,8,9 and 10] were not considered to be as suitable for reasons discussed later in this report (see Sections 2 and 4).

Apart from the 12:12:12 MHz *YUV* connection from the RGB input unit to the chroma-key unit, all video connections between units in the animation store are made via a video routing system (VRS) which provides six separate 12:4:4 MHz *YUV* video buses. The inputs and outputs of any unit in the store may be connected to these buses using switchable connection nodes under the control of the animation store control system. Units having connections to the video routing system include the chroma-key and mixer units, the disc-drive picture storage unit, three semi-conductor picture stores, the input unit which converts analogue PAL or RGB video signals to 12:4:4 MHz *YUV* video signals, and an output unit for converting 12:4:4 MHz *YUV* signals to an output PAL analogue video signal.

The video data on the video routing system is encoded as two separate 8-bit data streams, one carrying the 12 MHz sampled *Y* data and the other carrying multiplexed *U* and *V* data each sampled at 4 MHz. The 12:12:12 MHz *YUV* connection to the chroma-key unit is encoded as three separate 8-bit data streams, one for each of the *Y*, *U* and *V* signals sampled at 12 MHz

## 2. Basic mode of operation— Keying from 12:12:12 MHz *YUV* signals

### 2.1. General

In its basic mode of operation, the chroma-key unit replaces areas of a chosen colour in one

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*Also known as colour separation overlay or CSO.

*The author is grateful to M. Weston, who proposed the circuit arrangement described in Ref. 4, for very helpful discussions on the principles of linear, additive chroma-key.

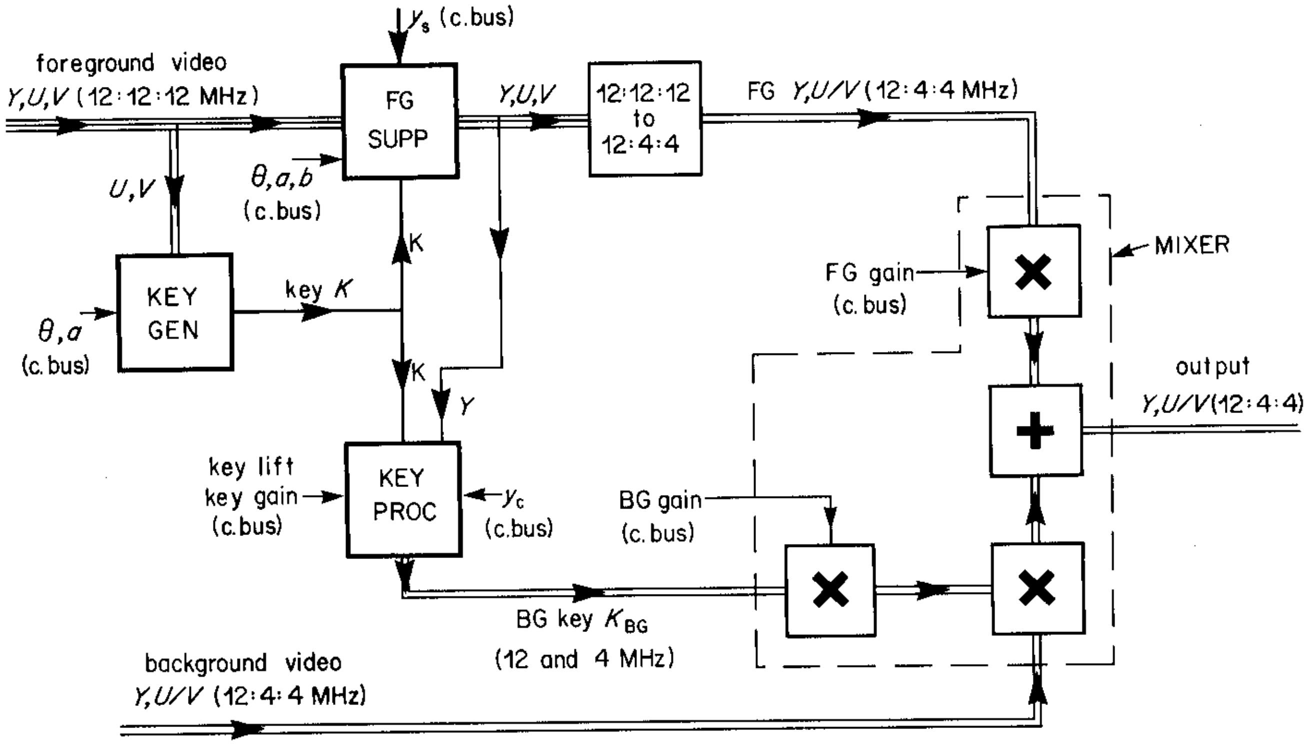

*Fig. 1 – Block diagram of chroma-key unit and mixer (FG = foreground, BG = background, c.bus* control bus)

television picture, to be referred to as the foreground (FG) picture, with corresponding areas from a second television picture, to be referred to as the background (BG) picture. In this way, foreground subjects can be made to appear as if they are situated in front of the background scene.

A block diagram of the chroma-key unit and associated mixer are shown in Fig. 1. In this diagram, the key signals which determine the areas of the foreground picture that are to be replaced, are derived from the foreground *U* and *V* components, each sampled at 12 MHz. Other forms of key signal processing are discussed later including the generation of key signals from *U* and *V* components sampled at 4 MHz and from the luminance component of the foreground signal.

For all types of key processing, the mixer unit connected to the chroma-key unit operates on 12 : 4 : 4 MHz *YUV* video signals.

Inputs marked "c.bus" in Fig. 1 are connected to the control bus which supplies data from the computer control system of the animation store. Further details of the circuitry shown in Fig. 1 are given below.

### 2.2. Key generator

In this unit, the *U* and *V* components of the foreground video signal are processed to provide a key signal which differentiates between colours close to a chosen key colour and the remaining colours in the foreground scene.

The first part of the processing involves a transformation of the foreground *U* and *V* components on to new axes, to be referred to as the *X* and *Z* axes. As indicated in Fig. 2, the *X* and *Z* axes are obtained by rotating the *U* and *V* axes, i.e. the axes used in vectorscope displays, through a hue angle $\theta$ which is adjusted so that the positive direction of the *X* axis passes through the chosen key colour co-ordinates. In practice, $\theta$ can be adjusted through 360° in steps of 1°.

The *X* and *Z* components of any foreground colour are related to its *U* and *V* components and the hue angle $\theta$ by the relationships:

$$X = U\cos\theta + V\sin\theta \qquad (1)$$

$$Z = V\cos\theta - U\sin\theta \qquad (2)$$

The key signal *K* is derived from the *X* and *Z* colour components using the expression:

$$K = X - a|Z|; \quad K = 0 \text{ if } X < a|Z| \qquad (3)$$

where $a$ is an adjustable constant

The resulting values of *K* obtained for *X* and *Z* values in the range $-1$ to $+1$ are illustrated in

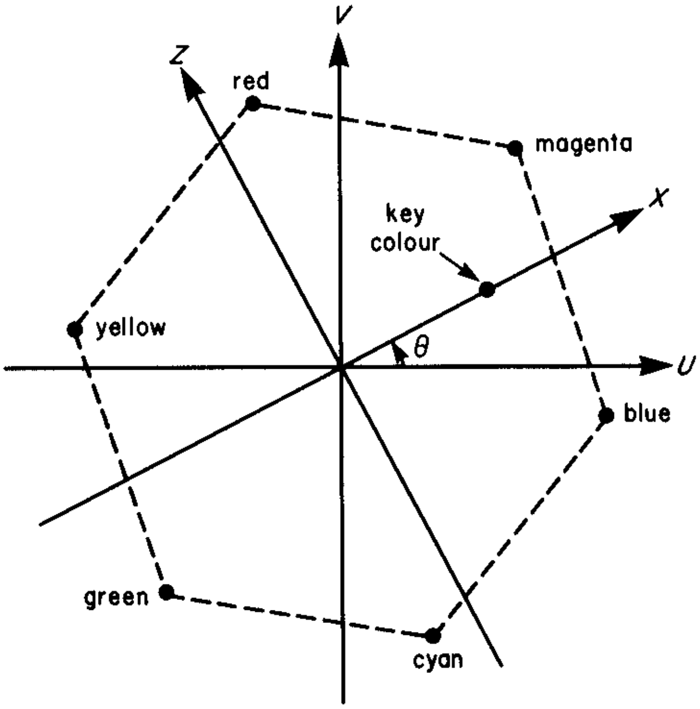

*Fig. 2 – X and Z axes obtained by rotating U and V axes through hue angle θ.*

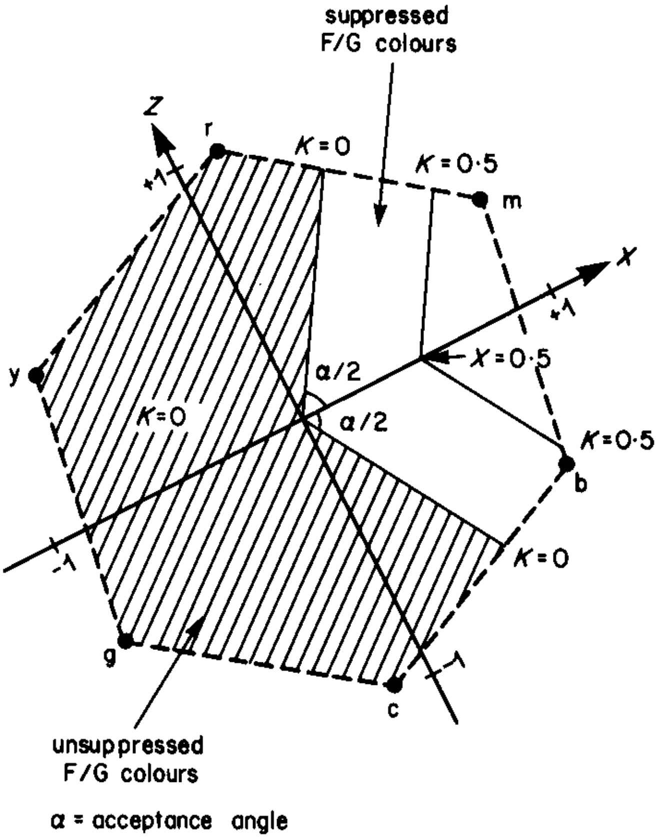

*Fig. 3 – Values of key signal K used for suppression of foreground signal*

Fig. 3. Any given non-zero value of $K$ corresponds to a pair of straight lines as shown for $K = 0.5$. In this figure, points marked r, y, g, c, b, m represent the 100% saturated colours red, yellow etc. This diagram is based on normalised values of $U$ and $V$ lying within the range $-1$ to $+1$*.

The "acceptance" angle $\alpha$ of the sector shown in Fig. 3 where $K$ is non-zero depends on the value of $a$ in Equation 3, the relationship being given by:

$$\alpha = 2 \tan^{-1} (1/a) \qquad (4)$$

In the equipment which has been constructed, values of $a = \frac{1}{2}$, 1, 2 and 4 are available giving values of $\alpha = 126°, 90°, 53°$ and $28°$.

It can be seen that the magnitude of $K$ obtained from any colour in the acceptance sector increases in a linear manner as its hue approaches the main key colour and as its saturation increases.

The key signal is filtered at the output of the key generator as discussed in Section 2.6.

### 2.3. Foreground suppressor

Coloured areas in the foreground picture having colour-difference components lying within the acceptance angle have their $Y$, $U$ and $V$ components reduced in the "FG Suppressor" of Fig. 1 by subtracting suitable proportions of the key signal $K$ from the foreground $YUV$ components, any colour on the central key axis being completely suppressed to black level. In the past, removal of the key colour has more commonly been achieved by multiplying the foreground signal components by a clipped version of the key signal giving unity gain in wanted foreground areas and zero gain in key-colour areas. The main advantages of the subtraction technique are that it gives softer edges at the key colour boundaries and that it avoids, in digital chroma-key, the generation of in-band alias components caused by multiplication and clipping processes.

For the simplest form of suppression, the foreground suppressor effectively reduces the foreground chrominance by subtracting the key signal from the chrominance signal $X$ i.e. the suppressed $X = X - K; Z$ is not affected. In practice, the circuitry performs the equivalent operations on the $U$ and $V$ signals, namely:

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*More precisely, the maximum and minimum values of the 8-bit digital $U$ and $V$ signals were assumed to be at quantisation levels 240 and 16 respectively as in CCIR Rec. 601. The $U$ and $V$ co-ordinates for the 100% saturated colours were then calculated in terms of these quantisation levels. Next, a normalisation process was applied which converted the range from 0 to 255 levels to the range $-1$ to $+1$. To obtain Fig. 3, the resulting co-ordinates of the saturated colours were plotted relative to $U$ and $V$ axes calibrated in normalised units and these axes were rotated without change of scale to give the $X$ and $Z$ axes calibrated as shown. The scales used in all diagrams in this report are based on the same normalisation process.

$$U_{\mathrm{SUP}} = U - K\cos\theta \qquad (5)$$

$$V_{\mathrm{SUP}} = V - K\sin\theta \qquad (6)$$

where $U_{\mathrm{SUP}}$ and $V_{\mathrm{SUP}}$ are the suppressed values of $U$ and $V$. These operations on the $U$ and $V$ signals are preferred because no processing of the $U$ and $V$ signals is required when $K = 0$.

The resulting effect on the colour-difference signals obtained along a line in the foreground picture in which the colour changes from red, in a wanted foreground subject, to a blue key colour are illustrated in Fig. 4(a).

The suppressed luminance component $Y_{\mathrm{SUP}}$ is given by:

$$Y_{\mathrm{SUP}} = Y - y_s K; \quad Y_{\mathrm{SUP}} = 0 \text{ if } y_s K > Y \qquad (7)$$

where $y_s$ is an adjustable constant. The luminance suppression parameter $y_s$ is normally adjusted so that $Y_{\mathrm{SUP}}$ is just clipped at zero, i.e. at black level, in the main key colour areas, as discussed in Section 5.

One disadvantage of this simple subtraction technique is that the $U$ and $V$ components of the foreground signal are set to zero only if they are lying exactly on the $X$ axis. As a result, any hue variations in key colour areas caused by noise or irregularities in the colour of the original picture are not entirely suppressed. To overcome this problem, circuitry has been included which sets the $U$ and $V$ components to zero for all colours which lie within a "suppression" sector of the $U$, $V$ plane. Like the "acceptance" sector, this suppression sector is symmetrically disposed on either side of the $X$ axis. Its included angle $\beta$ is adjustable from zero, as in simple subtraction, to a maximum of about one third the acceptance angle $\alpha$. For $\alpha = 90°$, the available values of $\beta = 0°$, $12°$, $22°$ and $36°$. The suppression of colours using a non-zero value of the suppression angle $\beta$ is shown in Fig. 4(b)*.

In addition to removing the key colour from the unwanted areas of the foreground picture, the suppressor also removes key-colour fringes on the wanted foreground subject caused by overspill of the key-colour; such fringe suppression has been used for some years together with multiplicative removal of the unwanted key-colour areas.$^6$

### 2.4. Key processor

This unit processes the key signal $K$ obtained from the key generator to obtain a background key signal $K_{\mathrm{BR}}$ which is used for removing the areas of the background picture where the foreground picture is to appear in the final chroma-keyed picture. This removal of foreground areas from the background picture is achieved by multiplying the background video signal by the background key signal $K_{\mathrm{BR}}$. $K_{\mathrm{BR}}$ must therefore be equal to zero in wanted foreground picture areas and equal to unity where the background picture is required with no attenuation. $K_{\mathrm{BR}}$ is obtained from the key signal $K$ by applying lift and gain adjustments followed by clipping at zero and unity values of $K_{\mathrm{BR}}$. For the range between $K_{\mathrm{BR}} = 0$ and $K_{\mathrm{BR}} = 1$, $K_{\mathrm{BR}}$ is related to $K$ by the expression:

$$K_{\mathrm{BR}} = (K - k_{\mathrm{L}})k_{\mathrm{G}} \qquad (8)$$

where the key lift ($k_{\mathrm{L}}$) and key gain ($k_{\mathrm{G}}$) parameters are applied to the key processor via the control system of the animation store and are continuously variable within their adjustable range.

Typical values of $K_{\mathrm{BR}}$ obtained from different colours in a foreground picture containing a blue backdrop for keying purposes are shown in Fig. 5.

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*The more complex suppression technique is based on the relationships:

$$X_{\mathrm{SUP}}(\text{suppressed value of } X) = X - (1 + b)K$$

$$Z_{\mathrm{SUP}}(\text{suppressed value of } Z) = Z \mp bK/a$$

In the expressions for $Z_{\mathrm{SUP}}$ above and for $U_{\mathrm{SUP}}$ and $V_{\mathrm{SUP}}$ below, the upper sign of "±" or "±" is used for positive values of $Z$ and the lower sign for negative $Z$. The value of $b$, which is set manually, determines the suppression angle $\beta$ obtained for a given acceptance angle, the relationship between $\beta$, $b$ and the acceptance parameter $a$ being

$$\beta = 2\tan^{-1}[b/a(1 - b)]$$

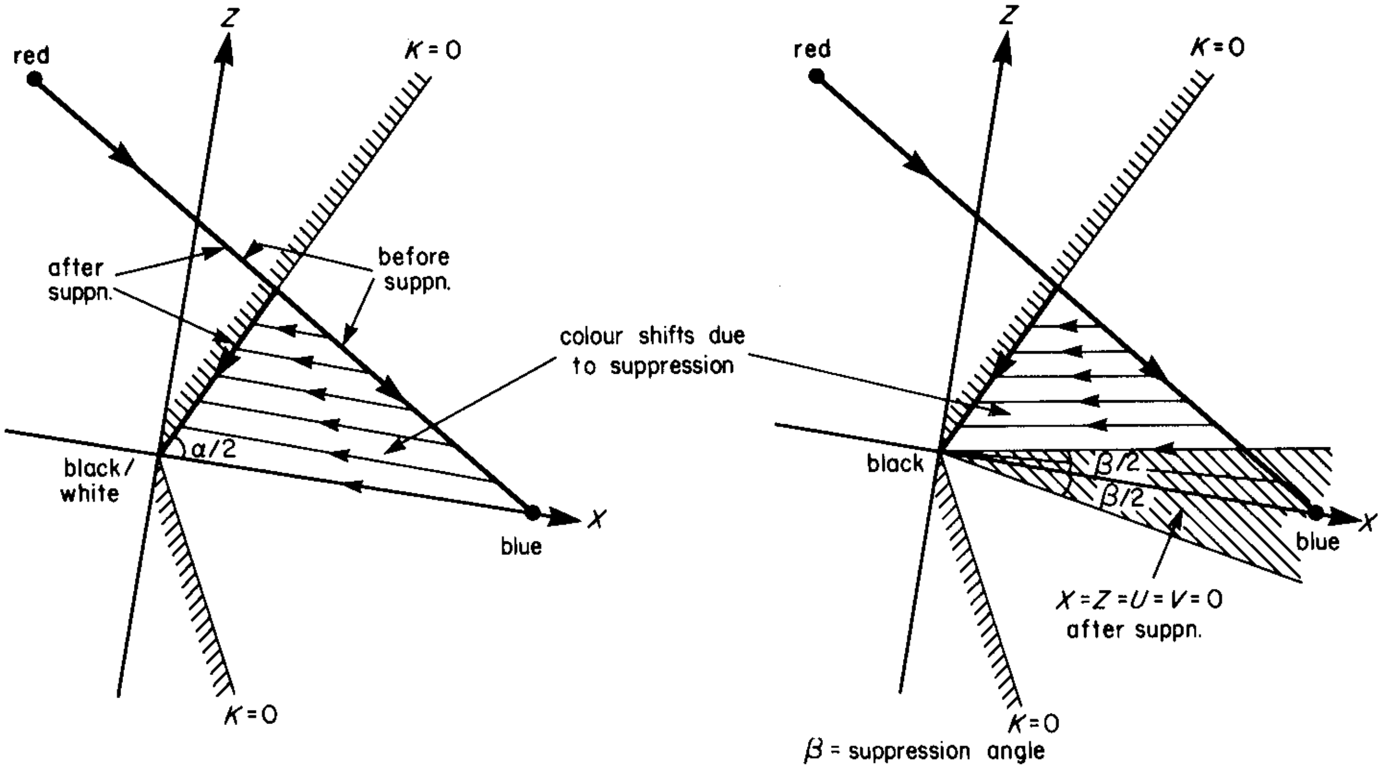
Values of $b = 0, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ have been instrumented giving values of $\beta = 0$, $12°$, $22°$, and $36°$ for $a = 1$ i.e. for an acceptance angle of $90°$.

In practice, the circuitry performs the equivalent operations on the $U$ and $V$ signals, namely:

$$U_{\mathrm{SUP}} = U - (1 + b)K\cos\theta \mp \frac{bK}{a}\sin\theta$$

$$V_{\mathrm{SUP}} = V - (1 + b)K\sin\theta \pm \frac{bK}{a}\cos\theta$$

Within the suppression sector, $U_{\mathrm{SUP}}$ and $V_{\mathrm{SUP}}$ are set to zero by detecting when $X < (1 + b)K$ (i.e. $X_{\mathrm{SUP}}$ would be negative) for positive values of $X$.



(a) (b)

*Fig. 4 – Effect of suppression on the chrominance components of a foreground picture for a gradual change from a wanted red subject to a blue key colour.*
*(a) Simple suppression; (b) Improved suppression*

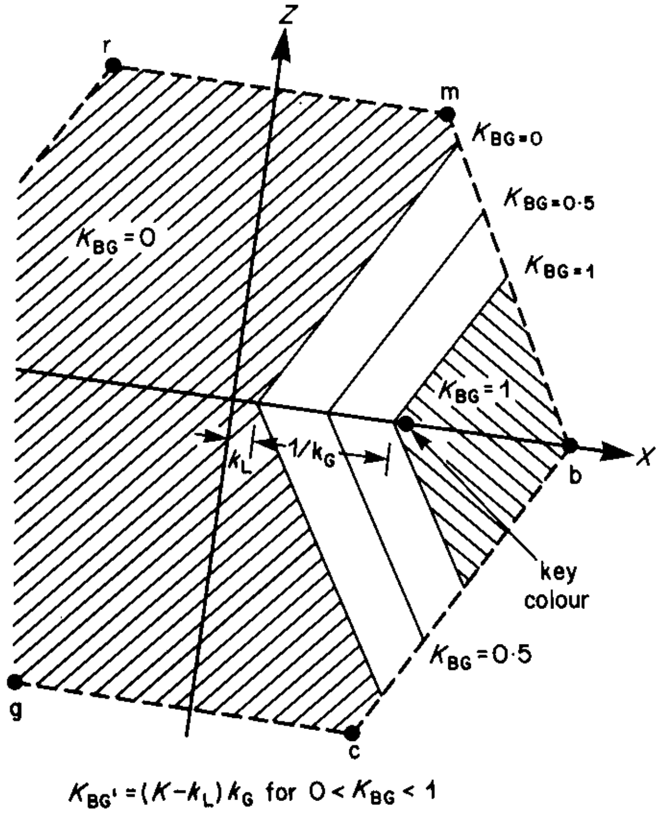


*Fig. 5 – Typical values of background key signal $K_{BG}$ for different foreground chrominance components.*

The transition band between $K_{BG} = 0$, and $K_{BG} = 1$ is made as wide as possible in order to minimise any discontinuities in the transitions between foreground and background areas in the combined picture. This requirement is fulfilled by low values of key lift and key gain whose adjustment is discussed in more detail in Section 5.

When shadows are cast by foreground objects on to key colour areas of the foreground picture, the resulting foreground chrominance values will typically lie along the $X$-axis in the linear range of $K_{BG}$ between 0 and 1. As a result the background signal is partially attenuated giving rise to shadow effects on the background picture. In a similar manner, attenuated background pictures can appear through transparent foreground objects situated in front of key-colour areas.

A further feature of the key processor enables the magnitude of the background key signal to be reduced as the luminance of the foreground signal increases. Thus, it is possible to arrange that, when the background signal is turned on fully in saturated blue areas of the foreground, it is not turned on, or only partially turned on, in desaturated blue areas.

The key signal $K'$ obtained after compensation for increasing luminance is given by:

$$K' = K - y_c Y_{SUP}; \quad K' = 0 \text{ if } y_c Y_{SUP} > K \qquad (9)$$

where $y_c$ is an adjustable constant.

In the main key-colour areas of the foreground picture, the luminance suppression is normally adjusted to give $Y_{SUP} = 0$, so that in these areas $K' = K$. In addition, $K' = K = 0$ for wanted objects in the foreground picture whose colour components lie outside the acceptance angle. Thus the only areas in the foreground picture for which $K'$ is less than $K$ are those whose colour lies within the acceptance sector and whose luminance is greater than that which is suppressed to zero.

The effect of luminance compensation on key values is illustrated in Fig. 6. This figure shows key values $K'$ and $K$ obtained for different values of the foreground $Y$ (luminance) and $X$ (chrominance) components when the $Z$ (chrominance) component is equal to zero i.e. for colours lying on the $X$-axis of previous figures. (In a 3-dimensional plot of the foreground $Y$, $X$ and $Z$ components, the plane formed by the $Y$ and $X$ axis as used for Fig. 6 would be perpendicular to the plane formed by the $X$ and $Z$ axis used in previous figures with the $X$ axis common to both planes.) Note that the numbers along the $X$-axis in Fig. 6 give values of $X$ or $K$ because, from Equation 3, $X = K$ when $Z = 0$.

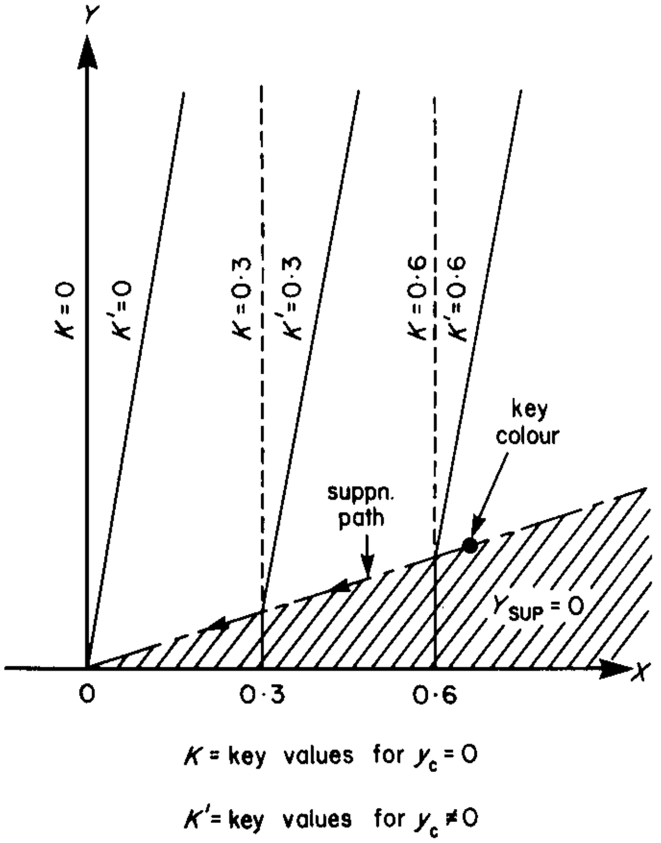


*Fig. 6 – Effect of the luminance compensation parameter $y_c$ on key values, shown for Y (luminance)/X (chrominance) plane in which $Z = 0$.*

The final background key signal is transmitted to the mixer as two 8-bit signals, one sampled at 12 MHz for applying to the luminance component of the background video signal, the other being sampled at 4 MHz for applying to the $U$ and $V$ components. The 4 MHz-sampled signal is derived from the 12 MHz sampled signal via an interpolating filter as discussed in Section 2.6. No filtering is applied to the 12 MHz signal in the key processor.

### 2.5. Mixer

The final picture is obtained by adding the suppressed foreground signal to the background signal multiplied by its key signal $K_{BR}$. This process takes place in the mixer which also allows the gain of each signal to be separately adjusted by means of 8-bit control signals giving a maximum gain of unity. A minimum of 8 bits for these gain control signals was found to be desirable in order to give the appearance of completely smooth fading for the most critical video signals e.g. a peak white signal over the whole picture area.

It should be noted that the simple multiplication of a video signal of magnitude $v$ by a gain factor $A$ as shown in Fig. 1 causes the output signal $A \times v$ to fade to zero when $A = 0$ rather than to the level corresponding to zero luminance or chrominance i.e. the 8-bit quantum levels 16 and 128 respectively, as given in CCIR Rec 601. To overcome this problem a correction factor equal to $(1 - A)v_o$ is added to the product $A \times v$ where $v_o$ is the required level of zero luminance or chrominance. Thus:

$$\text{Corrected video from fader} = Av + (1 - A)v_o \qquad (10)$$

It can be seen that when $A = 0$, then the corrected video output of the fader equals $v_o$ as required and when $A = 1$, the output $= v$. With $v_o = 16$ and 128, as specified for $Y$ and $U$ or $V$ in CCIR Rec. 601, the multiplication of $(1 - A)$ by $v_o$ simply involves a shifting operation in binary arithmetic.

### 2.6. Filtering and sample rate changing

Three separate digital filters are used in the process of obtaining chroma-key pictures from 12 : 12 : 12 $YUV$ foreground video signals.

Firstly, the 12 MHz-sampled *U* and *V* signals obtained from the foreground suppressor are passed through a filter in the 12:12:12 MHz to 12:4:4 MHz converter which is flat to about 1.4 MHz and −15 dB at 2 MHz. This filtering occurs prior to sub-sampling of the *U* and *V* signals at 4 MHz and is necessary to eliminate the alias components which would otherwise be generated by the sub-sampling process.[11] The same filtering and sub-sampling circuitry is used in the generation of all the 12:4:4 MHz *YUV* video signals required within the animation store. This alternative application is not required during keying from 12:12:12 MHz *YUV* signals because the background 12:4:4 MHz *YUV* signals have been filtered previously and then stored on the disc drive.

Secondly, low-pass filtering of the key signal at the output of the key generator was found to be desirable. The purpose of this filter is partly to reduce high-frequency noise in the key signal but is mainly to prevent unwanted keying off high-frequency picture detail in the wanted foreground areas. Such areas can generate key signals, even though no key colour is present in the original foreground picture, as a result of camera misregistration or unequal high-frequency gains in the RGB camera channels. Further work is required to determine the optimum low-pass filter for this purpose, but the existing filter which is flat to about 3 MHz, −6 dB at 4 MHz and −40 dB at 5 MHz appears to be satisfactory.

Thirdly, the background key signal $K_{BR}$ sampled at 12 MHz is passed through a 2 MHz low-pass filter and then re-sampled at 4 MHz in order to obtain a suitable version of $K_{BR}$ for applying to the 4 MHz-sampled *U* and *V* components of the background video signals. A simple slow-cut filter was found to be adequate for this purpose, its amplitude characteristic being −6 dB at 2 MHz and −40 dB at 4 MHz.

The 12 MHz sampled $K_{BR}$ signal is applied directly to the luminance component of the background video signal without filtering.

The filtering required when 12:4:4 MHz *YUV* signals are applied to the chroma-key unit is described in Section 3.2.

## 3. Other key facilities

### 3.1. General

Other facilities provided by the chroma-key and mixer units in the animation store will be explained with reference to the more detailed block diagram shown in Fig. 7. The video routing system (VRS) shown in this figure carries 12:4:4 MHz *YUV* video signals and interconnects all the units in the animation store as discussed in Section 1.

With the switches SW1, 2, 3, 4 and 5 in the positions shown in Fig. 7, the processing provided is the same as that described in Section 2, apart from the inclusion of a non-additive mixer where an external key signal and/or garbage matte* may be added to the chroma-key signal. (See Sections 3.4 and 3.5.) In particular, the magnitude of the foreground key signal $K_{FG}$ applied to the mixer is equal to unity for the given positions of SW1, SW2 and SW3. Thus no keying is applied in the mixer to the foreground video signal as required by the additive key technique.

With SW1 in its other position, the foreground video signal is multiplied in the mixer by $(1 - K_{BG})$ so that the foreground component of the mixer output is then turned off when the background component is turned on and vice versa. This multiplicative keying of the foreground video signal is used for luminance keying (see Section 3.3) and also when the video signal applied to key generator is not related to the foreground video signal applied to the mixer; under these conditions suppression of the foreground signal is not applicable.

The alternative positions of SW3 and SW4 making $K_{FG} = 1$ and $K_{BG} = 1$ are used when simple mixing with no keying is required.

Further details of the facilities provided by the arrangement shown in Fig. 7 are discussed below.

### 3.2. Keying from 12:4:4 *YUV* signals

Key signals limited in bandwidth to slightly under 2 MHz can be obtained from the 12:4:4 MHz *YUV* signals stored on the disc-drive. These stored video signals are supplied via the video routing system to the *U*,*V* de-multiplexer, the output of which is selected by SW5.

In the *U*,*V* de-multiplexer, two separate 4 MHz sampled *U* and *V* data streams are obtained from the multiplexed *U* and *V* data on the video routing system. These separate data streams are

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*A garbage matte is an electronically generated key signal which forces the mixer to produce the background signal alone within a given area of a chroma-keyed picture with normal keying taking place elsewhere.

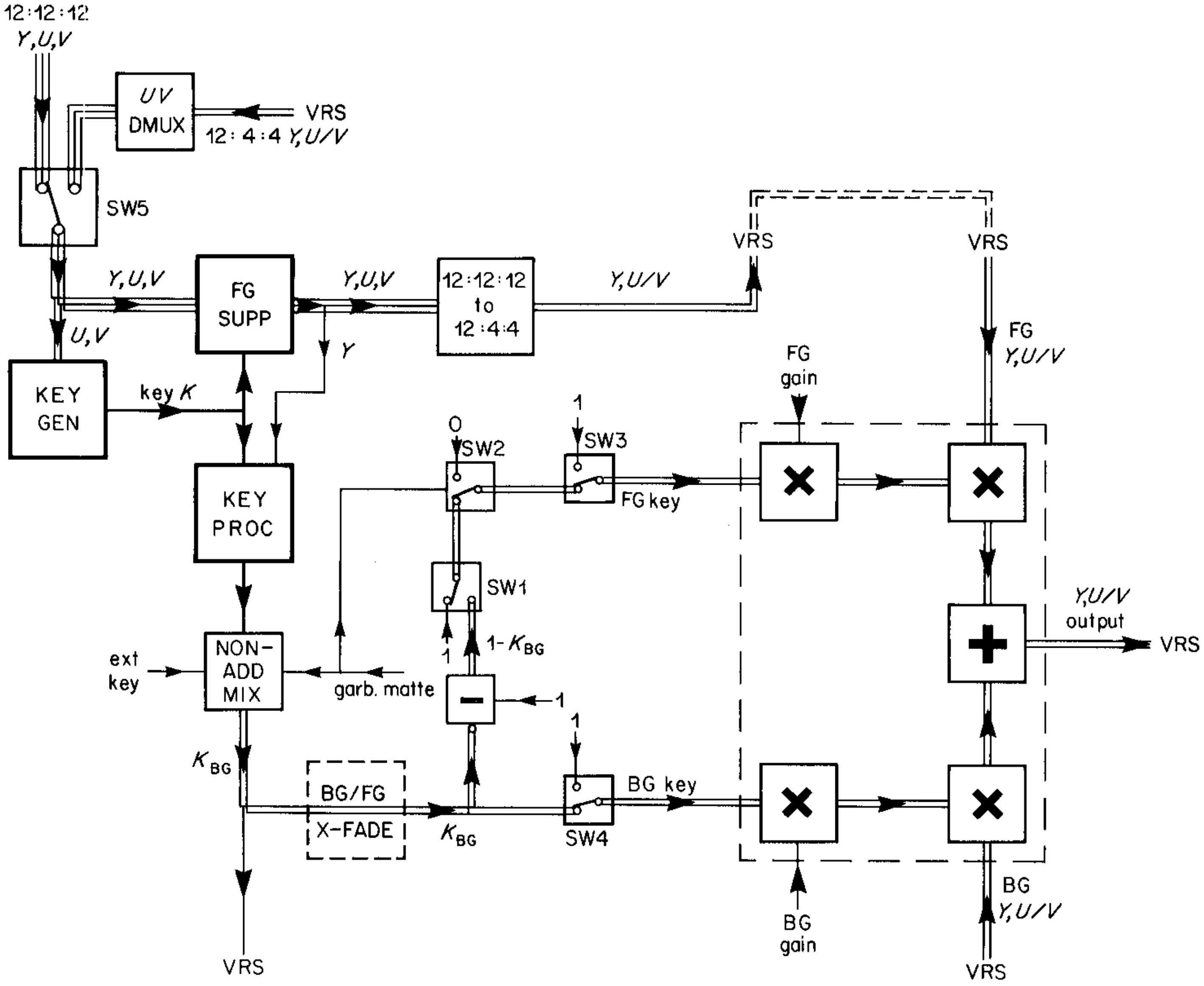

*Fig. 7 – More detailed block diagram of chroma-key and mixer units.*

then re-clocked at 12 MHz to make them compatible with the *U* and *V* data in the 12 : 12 : 12 MHz *YUV* input obtained directly from the rostrum camera input signals.

There are two main further alterations in the processing compared to that used for keying from 12 : 12 : 12 *YUV* signals as described in Section 2.

Firstly, the pass-band of the filter at the output of the key generator is reduced to 2 MHz to remove unwanted components between 0 and 12 MHz centred on 4 and 8 MHz. The characteristic which is employed is flat to about 1.5 MHz and −6 dB at 2 MHz; this characteristic overall includes the effect of re-clocking the 4 MHz *U* and *V* data at 12 MHz in the *U*,*V* demultiplexer. The resulting 12 MHz key signal is used in the same manner as the wider bandwidth 12 MHz key derived from the direct 12 : 12 : 12 MHz *YUV* foreground video signals, except that the unfiltered key signal is used in the suppression of *U* and *V* components as discussed in the next paragraph.

The second alteration involves a replacement of the complex 12 : 12 : 12 MHz to 12 : 4 : 4 MHz *YUV* converter including a 2 MHz low-pass filter (see Section 2.6) which follows the foreground suppressor by a simple converter in which the 12 MHz *U* and *V* data is sub-sampled at 4 MHz without filtering. No filtering is required in this sample-rate conversion process or for the key signal used to suppress the *U* and *V* data because the suppression of the *U* and *V* signals is effectively carried out at a 4 MHz sample rate with each sample being temporarily clocked at 12 MHz. This arrangement avoids the need for 2 MHz low-pass filters in the sample rate conversion of the $U$ and $V$ signals between 4 MHz and 12 MHz and between 12 MHz and 4 MHz.

In practice, the complex 12 : 12 : 12 MHz to 12 : 4 : 4 MHz converter including the 2 MHz low-pass filter is re-used to connect the 12 : 12 : 12 MHz $YUV$ signals to the 12 : 4 : 4 video routing system during keying from 12 : 4 : 4 MHz $YUV$ video signals. The associated switching is not shown in Fig. 7.

Summarising, the filtering required for keying from 12 : 4 : 4 MHz $YUV$ signals consists of three separate stages of low-pass filtering at 2 MHz, the associated processes being:

(a) the conversion of 12 : 12 : 12 MHz $YUV$ signals to 12 : 4 : 4 MHz $YUV$ signals (see Section 2.6).

(b) the generation of a 12 MHz-sampled key signal from re-clocked 4 MHz-sampled $U$ and $V$ signals (see this section).

(c) the generation of a 4 MHz-sampled key applied to the background video $U$ and $V$ components and obtained from the 12 MHz-sampled key $K_{BR}$ from the key processor. This filtering is identical to that used for keying from 12 : 12 : 12 MHz $YUV$ signals (see Section 2.6). It is probably not necessary but was left in for instrumental convenience.

### 3.3. Luminance keying

The luminance component of the foreground signal can be used to generate a key signal as an alternative to keying off its $U$ and $V$ components. Circuitry is available for insetting the background picture into either "white" or "black" parts of the foreground picture. For keying off "white" areas in the foreground picture, the keyed picture consists of entirely background above a certain foreground luminance level $Y_U$ and entirely foreground below a foreground luminance level $Y_L$ ($Y_L < Y_U$).

For levels between $Y_L$ and $Y_U$, there is a linear cross-fade between the foreground and background pictures. The key gain control adjusts the difference $Y_U - Y_L$ and the key lift increases or decreases $Y_U$ and $Y_L$ equally.

In this luminance key process, the key signal $K$ is set to zero so that no foreground suppression is applied and the background key signal $K_{BR}$ is generated in the key processor unit. The parts of the foreground picture which are not required are removed by multiplying the foreground signal by $(1 - K_{BG})$. Removal of the foreground signal by means of the suppression technique used for chrominance keying is not used for luminance keying, one reason being that the $U$ and $V$ components of the foreground signal cannot all be removed by a simple subtraction technique.

### 3.4. External key signal

An external key signal applied to a separate input to the animation store can be combined with the background key signal $K_{BR}$ in a non-additive mixer i.e. a mixer whose output is equal to its greatest input. The foreground video signal is keyed in a multiplicative manner by the external key even when additive keying is employed for the internal key signal. (Not indicated on Fig. 7.)

### 3.5. Garbage matte

The garbage matte key signal generated in the animation store forces the mixer to produce the background signal alone either on the outside or on the inside of a rectangular area in the picture with normal keying taking place elsewhere. The position of the edges of this rectangle are adjustable. A typical use of this garbage matte would be for keying in the background scene at the edges of a picture when a backdrop providing the key colour in the foreground scene is not large enough to completely fill the entire picture area. As shown in Fig. 7, this garbage matte is added to the background key signal in the same non-additive mixer as that used by the external key signal and also it switches the foreground key signal to zero at SW2.

### 3.6. Stored key signals

The animation store is capable of recording background key signals for later use. Stored key signals are distributed as a 12 MHz $Y$ signal along the 12 : 4 : 4 $YUV$ video routing system. This facility allows wideband keying from recorded data, thus largely overcoming the problem that only narrow-band colour keying is possible from the recorded 12 : 4 : 4 MHz $YUV$ video signals.

### 3.7. Foreground/Background cross-fade

This facility produces a cross-fade from a keyed picture containing both foreground and background details to a picture consisting of the background picture only. The associated processing is illustrated in Fig. 8. This figure shows that the required effect is obtained by further processing

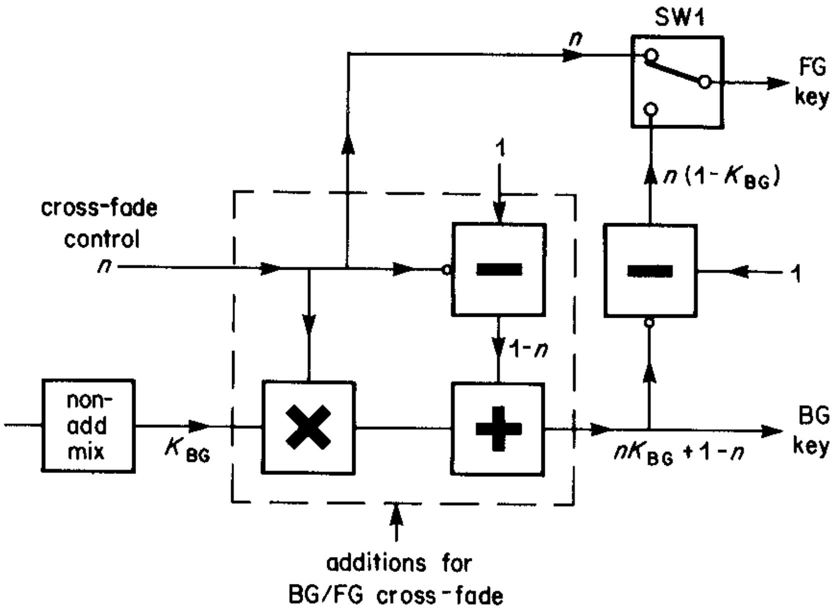

*Fig. 8 – Arrangement for producing a cross-fade between a keyed foreground background picture and a background picture alone. $n = 1$ gives keyed picture; $n = 0$ gives background picture alone.*

of the background key signal obtained from the non-additive mixer of Fig. 7 and by a further connection to switch SW1.

As indicated in Fig. 8, the new background key signal $K'_{BG}$ and foreground key signal $K'_{FG}$ are given by:

$$K'_{BG} = nK_{BG} + 1 - n \tag{11}$$

$$K'_{FG} = n \text{ ............ additive key} \tag{12}$$

$$= n(1 - K_{BG}) \text{ .... multiplicative key} \tag{13}$$

where $n$ is an adjustable cross-fade parameter.

It can be seen that when $n = 1$, then $K'_{BG} = K_{BG}$ and $K'_{FG} = 1$ or $(1 - K_{BG})$ as in normal keying. When $n = 0$, $K'_{BG}$ is set to unity and $K'_{FG}$ is set to zero thus resulting in a background only picture. Intermediate values of $n$ give varying proportions of the foreground and background pictures in the normally wanted foreground areas where $K_{BG} = 0$ which gives $K'_{BG} = 1 - n$ and $K'_{FG} = n$. However, for areas of a keyed picture containing only background detail i.e. where $K_{BG} = 1$, variations in $n$ have no effect because $K'_{BG} = 1$ thus leaving the background picture fully turned on and the foreground picture is turned off because it is suppressed with additive keying or it is multiplied by zero, i.e. $K'_{FG} = 0$, for multiplicative keying.

## 4. Digital problems

### 4.1. General

While digital processing provides improved stability and control of chroma-key compared to analogue processing, it can also introduce two forms of picture impairment, namely aliasing and quantising distortion, which do not occur with analogue processing and which can be more troublesome in the present application than in most other digital video processing operations.

### 4.2 Aliasing distortion

The normal method of ensuring that there are no significant alias components in the output signal from digital equipment is to employ low-pass filters at the input and output which remove components above one half the sampling frequency. However, non-linear clipping or multiplication of digital signals, as employed in chroma-key equipment, can introduce alias components into the wanted frequency band even though the input and output filtering is satisfactory for normal linear processing. Multiplication is more likely to cause trouble if the digital signals being multiplied are correlated, which is the case for the foreground video and key signals but not for the background video and key signals.

In the equipment being described, aliasing effects have been kept to a minimum by using a subtraction rather than a multiplication technique for removing the key-colour areas from the foreground picture and by avoiding unnecessary clipping of the key signal.

Alias components in the wanted frequency band of the key signal can also be generated as a result of a change in the sample rate of the key or $U$ and $V$ signals from 12 MHz to 4 MHz or vice versa.[11] In these processes, alias components are removed by the use of interpolating low-pass filters with a cut-off frequency of about one half the 4 MHz sample rate i.e. 2 MHz.

If necessary, alias effects caused by non-linear processing can be reduced by decreasing the bandwidths of the key signals to be somewhat less than half their sampling frequency but this will lower the resolution of the chroma-key effects. For keying from 12:12:12 *YUV* signals, no difficulty was experienced in obtaining sufficient resolution without introducing visible aliasing effects. However, for keying from 12:4:4 *YUV* signals, although aliasing effects were not obvious, there was a noticeable lack of resolution in the chroma-key process. The most relevant filters used for the 12:4:4 chroma-key were those in *U* and *V* signal paths prior to the key generator which were flat to about 1.4 MHz and −15 dB at 2 MHz, and the interpolating filter used in changing the sample rate of the key signal from 4 MHz to 12 MHz which was flat to about 1.4 MHz and −6 dB at 2 MHz. The results obtained with keying from 12:4:4 MHz *YUV* signals indicate that an increase in the bandwith of the *U* and *V* filters, and possibly that of the key filter, should give a better balance between resolution and freedom from aliasing.

### 4.3. Quantising distortion

The quantised nature of digital signals can be more noticeable in chroma-key processing than in most other digital video processing operations because of the limited range of *U* and *V* values available for keying purposes. With pictures from television cameras, the change in the *U* and/or *V* signals between the fully on and off values of the background key signal is typically about one quarter of the maximum possible changes in these signals. The resulting coarseness in the quantisation of the key signal is sufficient to cause visible quantising noise effects with 8 bits per sample *U* and *V* signals when there is a gradual change between foreground and background pictures or when shadows are being transmitted via the key signal. It is difficult to see how this problem can be overcome except by employing more bits per sample for the *U* and *V* signals. However, for the vast majority of chroma-keyed pictures, quantising effects are not noticeable, because transitions between foreground and background pictures are normally quite sharp.

## 5. Adjustment of controls

The chroma-key parameters are set via the computer which controls the entire operation of the animation store. Adjustments can be made using dedicated manual controls or by entering details on to a VDU display from a numeric keypad. Correct settings are most easily determined by examining a display of the output of the mixer using the procedure described below.

With the background picture turned off, the hue, $\theta$, control is adjusted so that the chrominance in the key-colour areas of the foreground picture is suppressed as far as possible. This adjustment is normally carried out with the narrowest acceptance and suppression angles ($\alpha = 28°$, $\beta = 0°$). The acceptance angle is then made as wide as possible without causing any significant suppression of wanted foreground colours and the suppression angle is set as narrow as possible consistent with good suppression of chrominance in the key colour areas. (Narrow acceptance and wide suppression angles are undesirable because they tend to cause harsh and noisy transitions between foreground and background pictures). The processing of the foreground picture is completed by adjusting the luminance suppression $y_S$ control so that the luminance $Y_{SUP}$ in the main key colour areas is just clipped at black level.

Adjustment of the keying of the background picture is carried out in the following manner with the foreground picture turned off.

Firstly, with the luminance compensation switched off ($y_c = 0$), the key lift control is adjusted for minimum lift, i.e. $k_L$ should be close to zero, consistent with good keying to black of the background picture where the output picture should consist of foreground only.

Secondly, the luminance compensation parameter, $y_c$ can be increased to improve keying to black of the background picture for wanted foreground colours close to the key colour but of higher luminance. However, increasing $y_c$ tends to worsen the appearance of some foreground to background transitions and this should be checked on the combined foreground and background pictures. For most pictures, $y_c = 0$ gives the best overall results.

Thirdly, the key gain $k_G$ control is adjusted so that the contrast of the background picture just reaches its maximum value, i.e. $K_{BG} = 1$, in all the main key colour areas.

Finally, slight adjustments to the controls can be made on the combined foreground and background pictures. For example, small adjustments of the key gain, $k_G$ and luminance suppression, $y_c$

controls may slightly improve the overall appearance of the chroma-key process.

## 6. Conclusions

A 12:12:12/12:4:4 MHz *YUV* digital chroma-key system has been designed and implemented in an electronic rostrum camera animation system. Excellent results are achieved at 12:12:12 MHz. Results at 12:4:4 MHz are good but they support the view that the CCIR move to 13.5:6.75:6.75 MHz is worthwhile because of the benefit to chroma-key of wider bandwidth *U* and V signals, irrespective of other benefits.

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Printed by BBC RESEARCH DEPARTMENT, Kingswood Warren, Tadworth, Surrey, KT20 6NP